Overview: That "Mystery of Mysteries"

- In the Galápagos Islands Darwin discovered plants and animals found nowhere else on Earth
- **Speciation** is the process by which one species splits into two or more species
  - Speciation explains the features shared between organisms due to inheritance from their recent common ancestor

- Speciation forms a conceptual bridge between microevolution and macroevolution
- **Microevolution** consists of changes in allele frequency in a population over time
- **Macroevolution** refers to broad patterns of evolutionary change above the species level

Animation: Macroevolution
Right click slide / Select play

Concept 22.1: The biological species concept emphasizes reproductive isolation

- *Species* is a Latin word meaning “kind” or “appearance”
- Biologists compare morphology, physiology, biochemistry, and DNA sequences when grouping organisms

The Biological Species Concept

- According to the **biological species concept:**
  - A **species** is a group of populations whose members have the potential to interbreed in nature and produce viable, fertile offspring
  - They do not breed successfully with other populations
- Gene flow occurs between the different populations of a species
  - This the populations together genetically
- The absence of gene flow plays a key role in the formation of new species

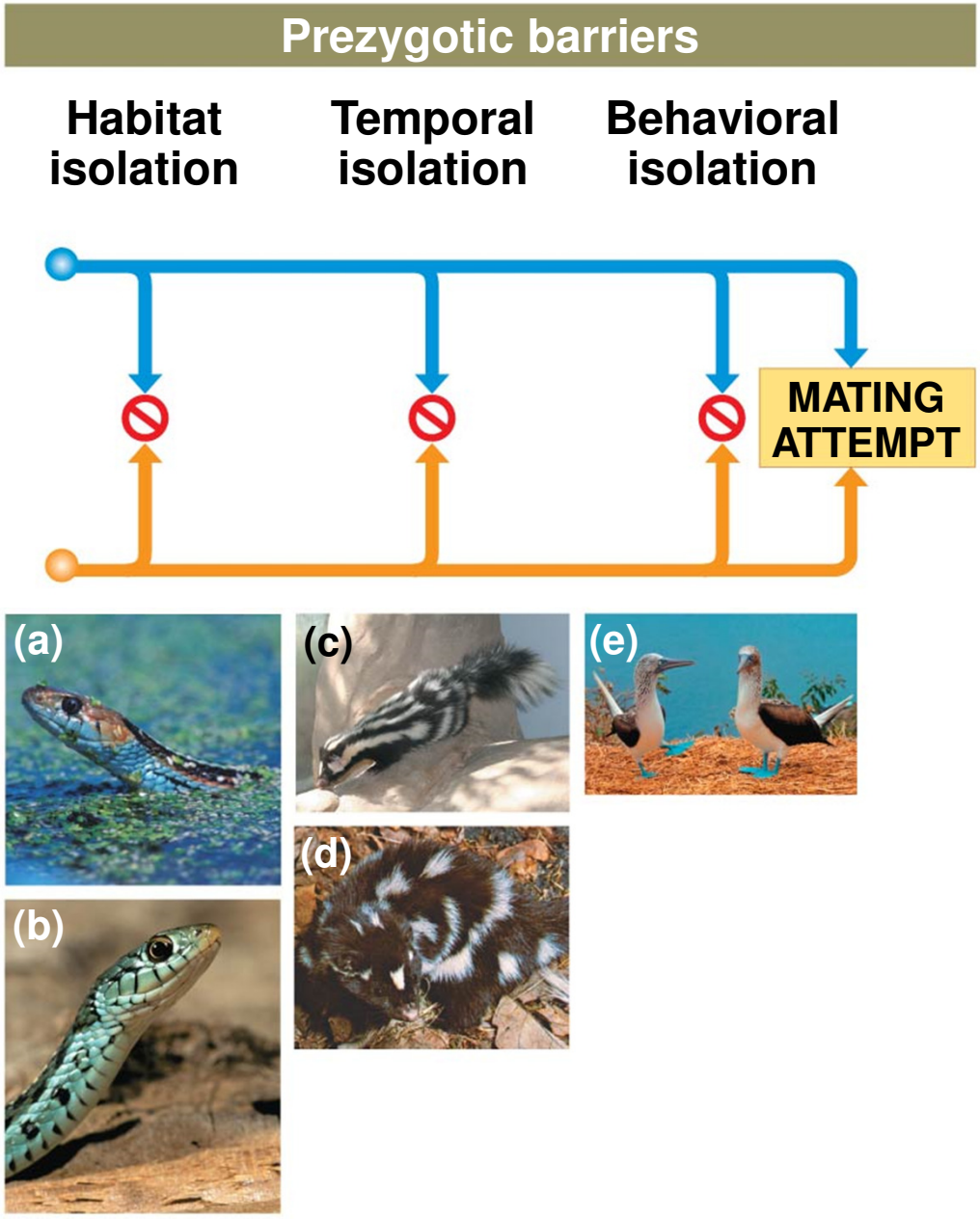
Reproductive Isolation

- **Reproductive isolation** is the existence of biological barriers that impede two species from producing viable, fertile offspring
  - Blocks gene flow between species
  - Limits formation of **hybrids**
    - The offspring of crosses between different species
- Reproductive isolation can be classified by whether barriers act before or after fertilization

- **Prezygotic barriers** block fertilization from occurring by
  - Impeding different species from attempting to mate
  - Preventing the successful completion of mating
  - Hindering fertilization if mating is successful

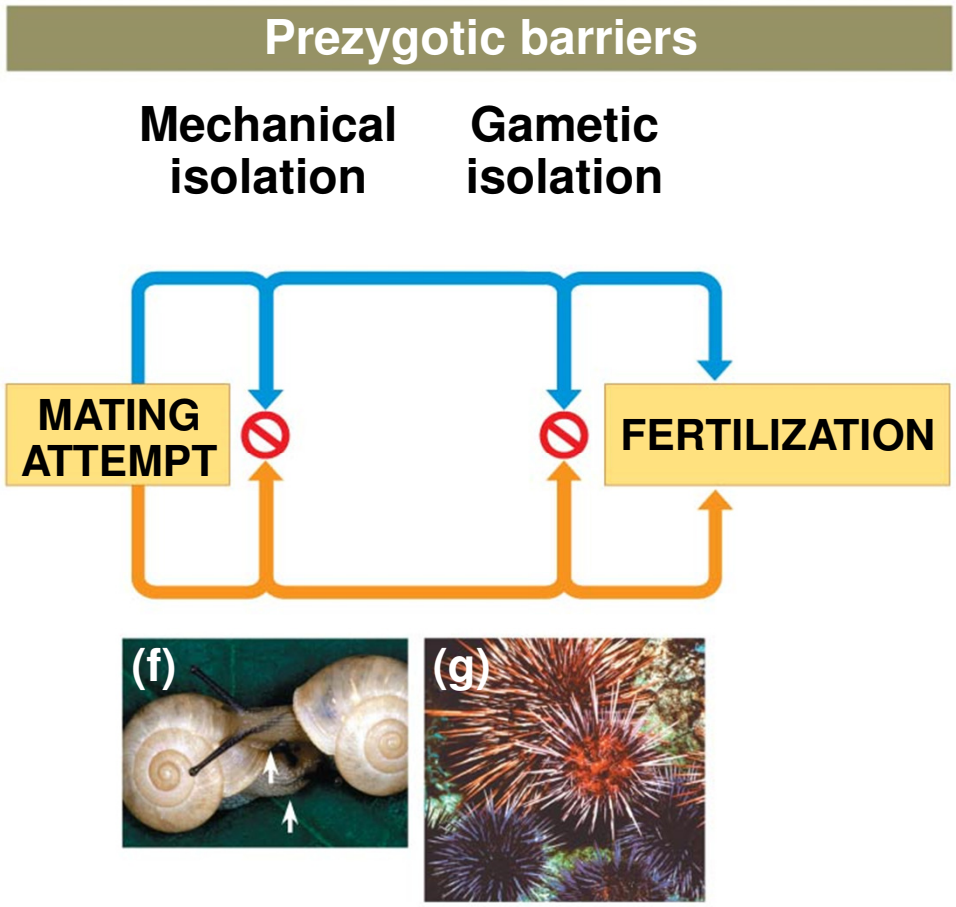
- **Habitat isolation**:
  - Two species encounter each other rarely, or not at all, because they occupy different habitats, even though not isolated by physical barriers
- **Temporal isolation**:
  - Species that breed at different times of the day, different seasons, or different years cannot mix their gametes
- **Behavioral isolation**:
  - Courtship rituals and other behaviors unique to a species are effective barriers

Figure 22.3a


Prezygotic barriers
Habitat isolation
Temporal isolation
Behavioral isolation
MATING ATTEMPT
(a)
(b)
(c)
(d)
(e)

- **Mechanical isolation**:
  - Morphological differences prevent successful mating
- **Gametic isolation:**
  - Sperm of one species may not be able to fertilize eggs of another species

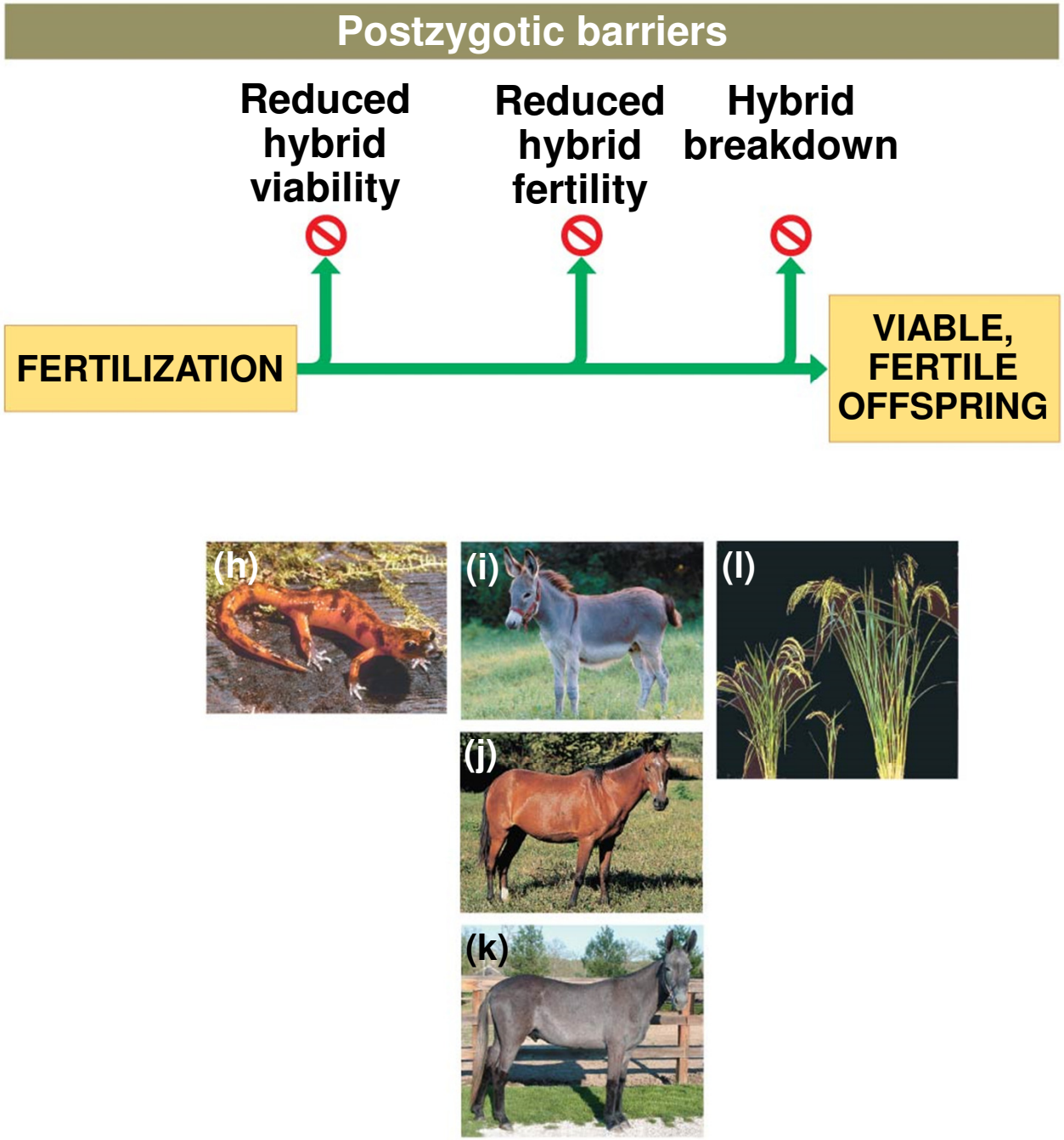
Figure 22.3b


Prezygotic barriers
Mechanical isolation
Gametic isolation
MATING ATTEMPT
FERTILIZATION
(f)
(g)

- **Postzygotic barriers** prevent the hybrid zygote from developing into a viable, fertile adult by
  - Reduced hybrid viability
  - Reduced hybrid fertility
  - Hybrid breakdown

- **Reduced hybrid viability**:
  - Genes of the different parent species may interact and impair the hybrid's development or survival
- **Reduced hybrid fertility**:
  - Even if hybrids are vigorous, they may be sterile
- **Hybrid breakdown**:
  - Some first-generation hybrids are fertile, but when they mate with another species or with either parent species, offspring of the next generation are feeble or sterile

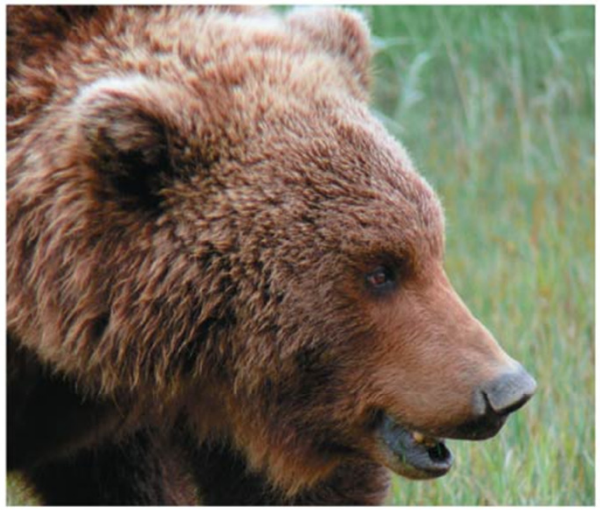
Figure 22.3c


Postzygotic barriers
Reduced hybrid viability
Reduced hybrid fertility
Hybrid breakdown
FERTILIZATION
VIABLE, FERTILE OFFSPRING
(h)
(i)
(j)
(k)
(l)

Limitations of the Biological Species Concept

- The biological species concept cannot be applied to fossils or asexual organisms (including all prokaryotes)
- The biological species concept emphasizes absence of gene flow
- However, gene flow can occur between distinct species
  - For example, grizzly bears and polar bears can mate to produce “grolar bears”

Figure 22.4



Grizzly bear (*U. arctos*)

Polar bear (*U. maritimus*)

Hybrid “grolar bear”

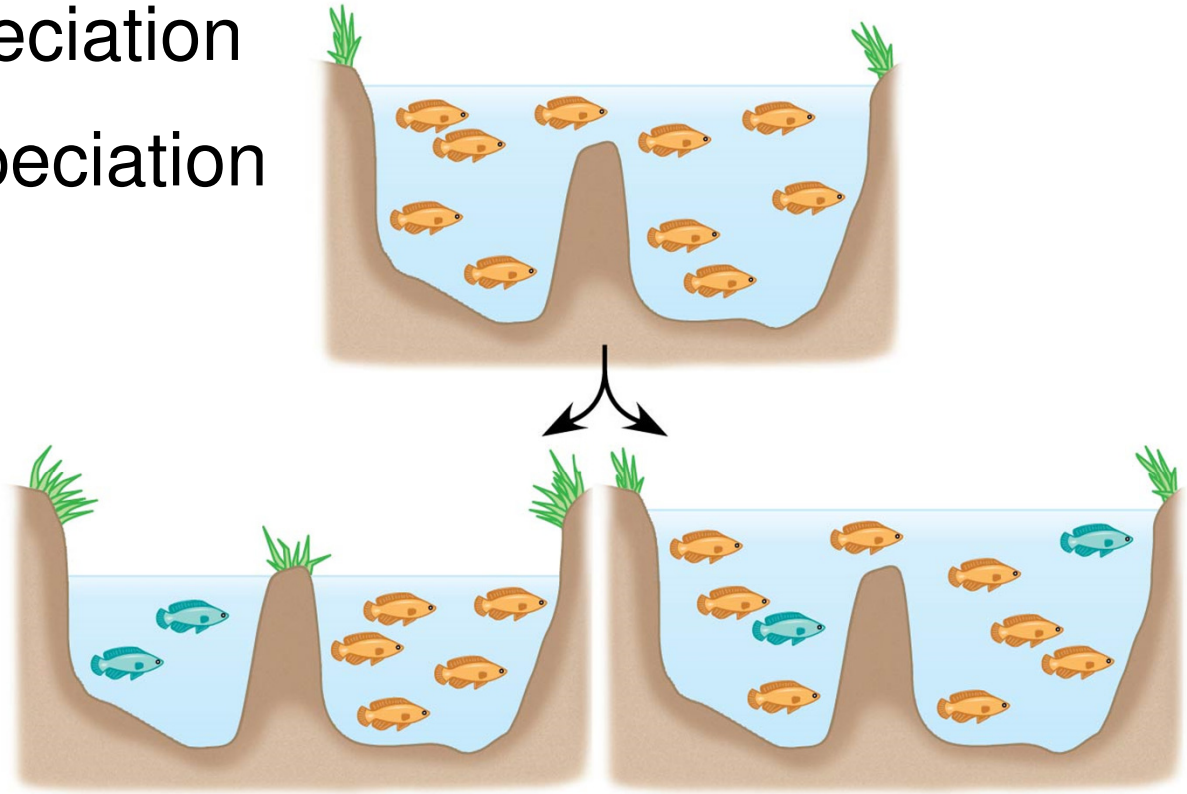
Other Definitions of Species

- Other species concepts emphasize the unity within a species rather than the separateness of different species
- The **morphological species concept** defines a species by body shape and other structural features
  - It applies to sexual and asexual species
  - But relies on subjective criteria

- The **ecological species concept** views a species in terms of its ecological niche (interactions)
  - It applies to sexual and asexual species
  - Emphasizes the role of disruptive selection
- The **phylogenetic species concept** defines a species as the smallest group of individuals on a phylogenetic tree
  - It applies to sexual and asexual species
  - But it can be difficult to determine the degree of difference required for separate species

Concept 22.2: Speciation can take place with or without geographic separation

- Speciation can occur in two ways
  - Allopatric speciation
  - Sympatric speciation



Allopatric speciation: Forms a new species while geographically isolated.

Sympatric speciation: a subset forms a new species without geographic separation.

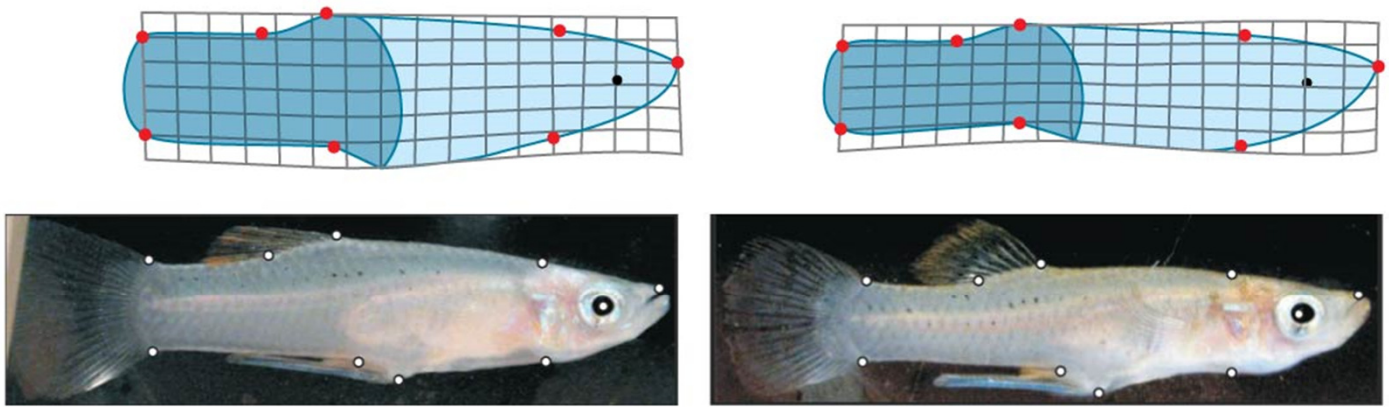
Allopatric ("Other Country") Speciation

- In **allopatric speciation**, gene flow is interrupted when a population is divided into geographically isolated subpopulations
  - Ex: Flightless cormorant of the Galápagos likely originated from a flying species on the mainland

The Process of Allopatric Speciation

- The definition of a geographic barrier depends on the ability of a population to disperse
  - For example, a canyon may create a barrier for small rodents, but not birds, coyotes, or pollen
- Separate populations may evolve independently through mutation, natural selection, and genetic drift
- Reproductive isolation may arise as a result of genetic divergence
  - For example, mosquitofish in the Bahamas comprise several isolated populations in different ponds

Figure 22.6



(a) Under high predation: body shape that enables rapid bursts of speed

(b) Under low predation: body shape that favors long, steady swimming

Evidence of Allopatric Speciation

- Regions with many geographic barriers typically have more species than do regions with fewer barriers
- Reproductive isolation between populations generally increases as the geographic distance between them increases

Sympatric ("Same Country") Speciation

- In **sympatric speciation**, speciation takes place in populations that live in the same geographic area
  - Less common than allopatric speciation
- Sympatric speciation occurs when gene flow is reduced between groups that remain in contact through factors including
  - Polyploidy
  - Habitat differentiation
  - Sexual selection

Polyploidy

- **Polyploidy** is the presence of extra sets of chromosomes due to accidents during cell division
  - Much more common in plants than in animals
  - Many important crops (oats, cotton, potatoes, tobacco, and wheat) are polyploids

- An **autopolyploid** is an individual with more than two chromosome sets, derived from one species
  - The offspring of matings between autopolyploids and diploids have reduced fertility

- An infertile hybrid may be able to reproduce asexually
- In future generations, a sterile hybrid can be changed into a fertile polyploid called an **allopolyploid**
  - A species with multiple sets of chromosomes derived from different species
  - Allopolyploids cannot interbreed with either parent species

Habitat Differentiation and Sexual Selection

- Sympatric speciation can also result from the appearance of new ecological niches
  - For example, the North American maggot fly can live on native hawthorn trees as well as more recently introduced apple trees

- Sexual selection can drive sympatric speciation
  - Sexual selection for mates of different colors has likely contributed to speciation in cichlid fish in Lake Victoria

Allopatric and Sympatric Speciation: *A Review*

- In allopatric speciation, geographic isolation restricts gene flow between populations
- Reproductive isolation may then arise by natural selection, genetic drift, or sexual selection in the isolated populations
- Even if contact is restored between populations, interbreeding is prevented by reproductive barriers

- In sympatric speciation, a reproductive barrier isolates a subset of a population without geographic separation from the parent species
- Sympatric speciation can result from polyploidy, natural selection, or sexual selection

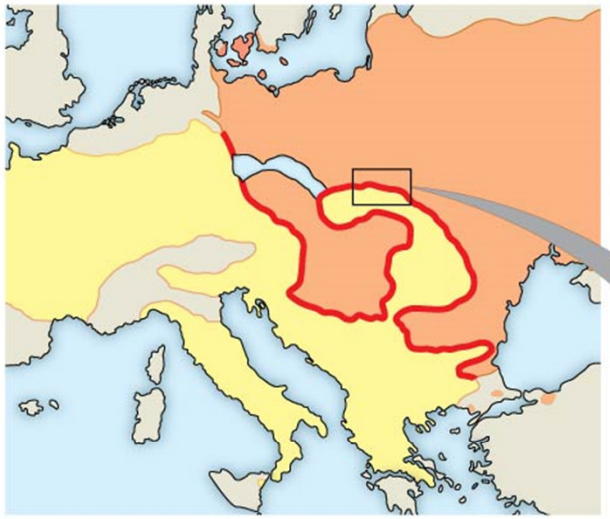
Concept 22.3: Hybrid zones reveal factors that cause reproductive isolation

- A **hybrid zone** is a region in which members of different species mate and produce hybrids
- Hybrids are the result of mating between species with incomplete reproductive barriers

Patterns Within Hybrid Zones

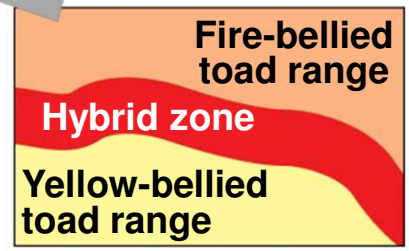
- A hybrid zone can occur in a single band where adjacent species meet
  - For example, two species of toad in the genus *Bombina* interbreed in a long and narrow hybrid zone
- Hybrids often have reduced fitness compared with parent species
- The distribution of hybrid zones can be more complex if parent species are found in patches within the same region

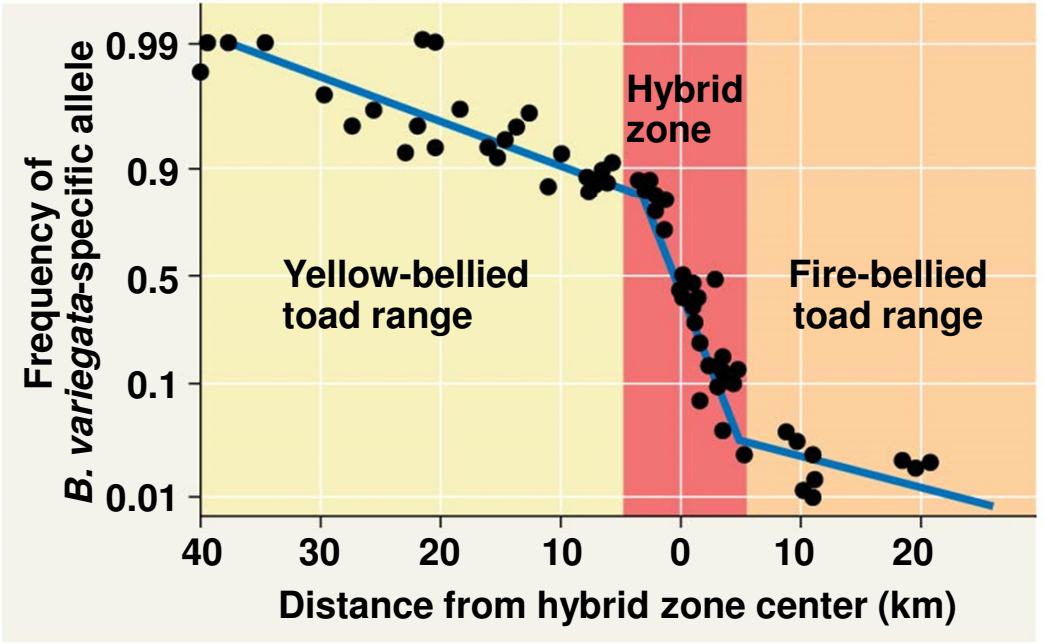
Figure 22.11



Fire-bellied toad, *Bombina bombina*

Yellow-bellied toad, *Bombina variegata*

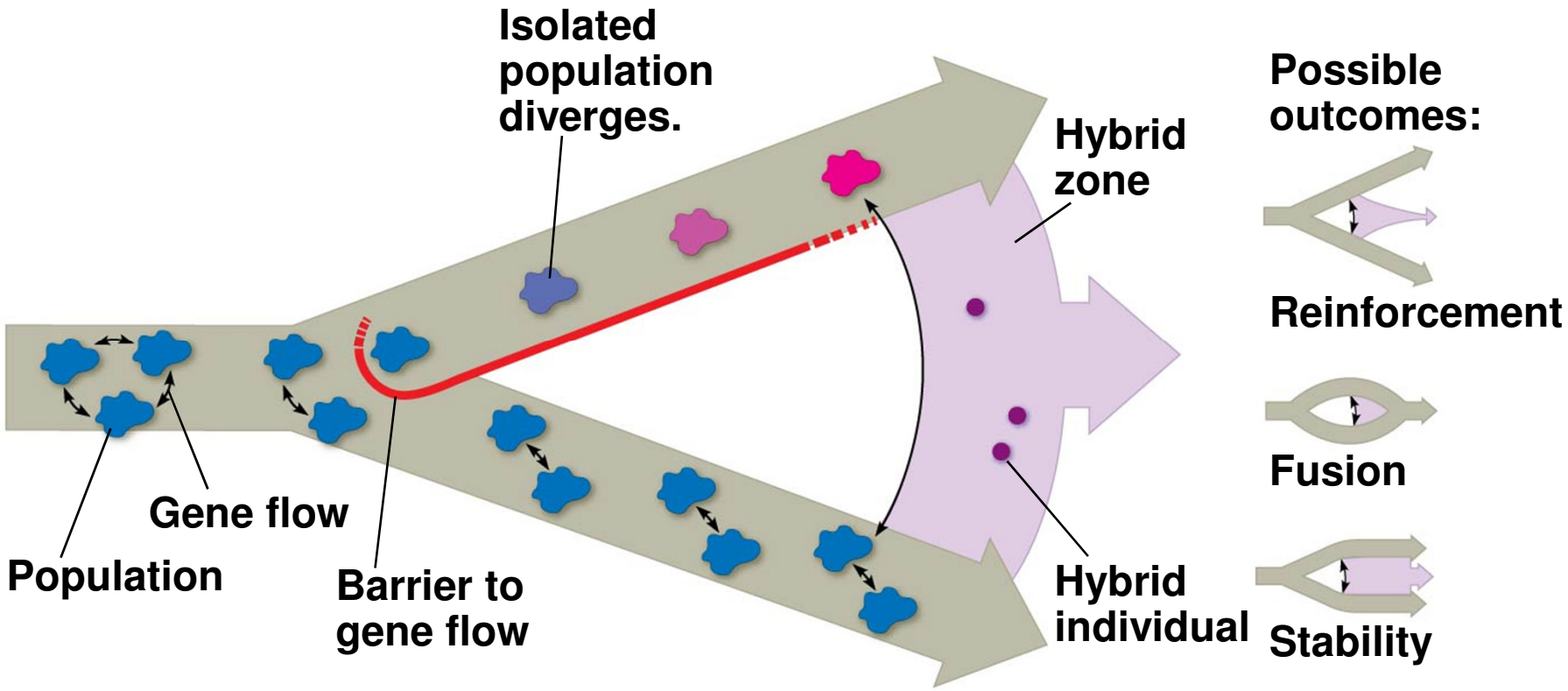




Hybrid Zones over Time

- When closely related species meet in a hybrid zone, there are three possible outcomes
  - Reinforcement
  - Fusion
  - Stability

Figure 22.12-4



- **Reinforcement** occurs when hybrids are less fit than the parent species
- Natural selection strengthens (reinforces) reproductive barriers, and, over time, the rate of hybridization decreases

- **Fusion** of the parent species into a single species may occur if hybrids are as fit as parents, allowing substantial gene flow between species
  - Speciation process reverses
  - For example, researchers think that pollution in Lake Victoria has reduced the ability of female cichlids to distinguish males of different species

- **Stability** of the hybrid zone may be achieved if extensive gene flow from outside the hybrid zone can overwhelm selection for increased reproductive isolation inside the hybrid zone
- In a stable hybrid zone, hybrids continue to be produced over time

Concept 22.4: Speciation can occur rapidly or slowly and can result from changes in few or many genes

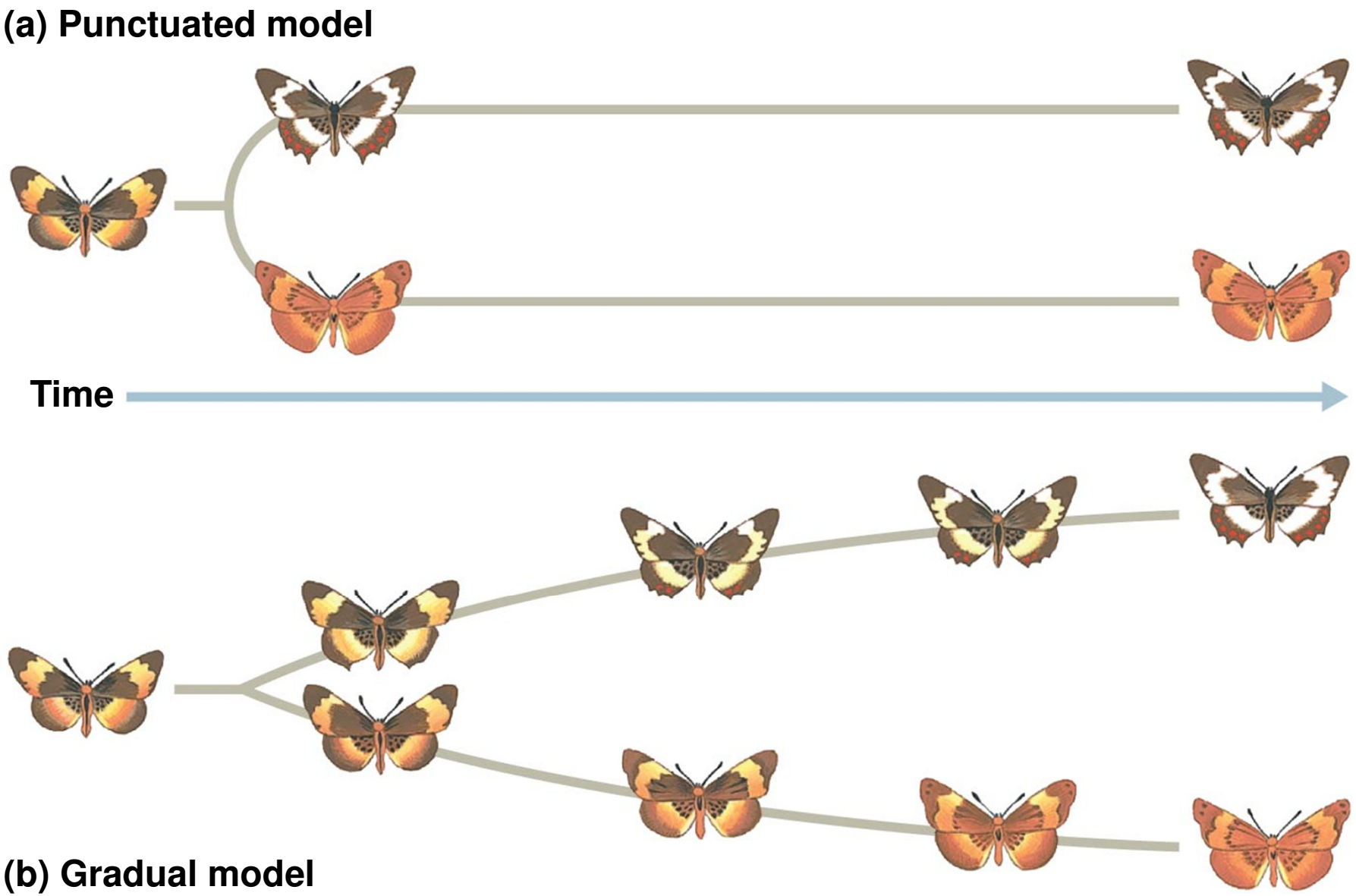
- Many questions remain concerning how long it takes for new species to form, or how many genes need to differ between species

- Broad patterns in speciation can be studied using the fossil record, morphological data, or molecular data

Patterns in the Fossil Record

- The fossil record includes examples of species that appear suddenly, persist essentially unchanged for some time, and then apparently disappear
  - These periods of apparent stasis punctuated by sudden change are called **punctuated equilibria**
- The punctuated equilibrium model contrasts with a model of gradual change in a species' existence

Figure 22.14



Speciation Rates

- The punctuated pattern in the fossil record and evidence from lab studies suggest that speciation can be rapid
  - For example, the sunflower *Helianthus anomalus* originated from the hybridization of two other sunflower species and quickly diverged into a new species

- The interval between speciation events can range from 4,000 years (some cichlids) to 40 million years (some beetles), with an average of 6.5 million years

- Speciation begins only after gene flow between population is interrupted
- Once gene flow is interrupted, the populations must diverge genetically to the point where they become reproductively isolated

Studying the Genetics of Speciation

- A fundamental question of evolutionary biology persists: How many genes change when a new species forms?
- Depending on the species in question, speciation might require the change of only a single allele or many alleles
  - For example, in Japanese *Euhadra* snails, the direction of shell spiral affects mating and is controlled by a single gene
  - In monkey flowers (*Mimulus*), two loci affect flower color, which influences pollinator preference

From Speciation to Macroevolution

- Macroevolution is the cumulative effect of many speciation and extinction events